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Supporting Combined-Arms Combat Capability with Shared Electronic Maintenance Facilities

William G. Wild, Jr.

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PREFACE

This is the third in a series of RAND reports examining the influence of high technology on the support of prime U.S. Army weapon systems. Companion publications on the M1 Abrams tank and the AH-64 Apache helicopter highlighted the value of responsive logistics structures in coping with these expensive and difficult-to-maintain systems.[1] The present study builds on those efforts and develops an integrated assessment of two high-technology weapon systems—the M1 and the M2/M3 Bradley Fighting Vehicle—that must contend against each other for critical but limited test diagnostic resources. This contention creates interdependence between M1 and Bradley combat availabilities and, consequently, among M1 and Bradley support resource investments as well. The analysis here also holds lessons for other shared maintenance facilities such as the forthcoming Integrated Family of Test Equipment (IFTE).

This research topic was suggested to the Army by the Arroyo Center because the introduction of sophisticated electronic systems in Army armor and aviation weapon systems threatens to complicate logistics support in the same way it has complicated Air Force logistics support. The concepts, tools, and techniques developed by RAND's Project AIR FORCE over the past decade should therefore prove very useful. This research provides the vehicle to test these concepts, tools, and techniques in an Army setting.

This work is part of the Readiness and Sustainability Program of RAND's Arroyo Center. The research project, "Improving Combat Capability through Alternative Support Structures," was sponsored by the U.S. Army Training and Doctrine Command's (TRADOC's) Logistics Center. The research should be of interest throughout the Army logistics community. A draft of this report was circulated to the Army in April 1989.

THE ARROYO CENTER

Operated by The RAND Corporation, the Arroyo Center is the U.S. Army's federally funded research and development center for studies

[1]See Morton B. Berman et al., *Evaluating the Combat Payoff of Alternative Logistics Structures for High-Technology Subsystems*, The RAND Corporation, R-3673-A, October 1988. Hereinafter this citation will be referred to as "Berman-1988." At this time the second report has been released in draft form only.

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Stephen M. Drezner is Vice President for the Army Research Division and Director of the Arroyo Center. Those interested in further information concerning the Arroyo Center should contact his office directly:

Stephen M. Drezner
The RAND Corporation
1700 Main Street
P.O. Box 2138
Santa Monica, CA 90406-2138
Telephone: (213) 393-0411

SUMMARY

THE CHALLENGE

The U.S. Army's M1 main battle tank and M2/M3 Bradley Fighting Vehicle both depend significantly on the Direct Support Electrical Systems Test Set (DSESTS) for fault diagnosis. This is indicative of a wider trend within the Army, which shows signs of shifting away from using "weapon-systems-specific" test diagnostic equipment and toward using more broadly capable versions that can isolate faults within subsystems and components from a number of different weapon systems. As an example, the proposed Integrated Family of Test Equipment (IFTE) is envisioned as a single test stand that could be used to diagnose high-technology components from approximately 20 different systems, ranging from missiles to tanks and radars.

With the advent of IFTE-like facilities, the dynamics underlying weapon-systems availability take a new turn. Weapon systems that once had uncontested access to specialized test equipment will now be relying on a common facility. As a result, their fates become linked: decisions made about the support of one weapon system can affect the availability of the others. This report demonstrates the importance of taking such linkages into account when making investment and operating decisions for support resources and suggests a methodology for doing so. It focuses particularly on expensive and difficult-to-maintain high-technology weapon systems.

PROJECT GOALS

The primary goal of this research is to demonstrate the value that a multiple-weapon-systems analysis can have in helping the Army achieve more robust support structures and greater weapon-systems availability from limited budgets.

A secondary goal is to provide a model analysis employing new techniques that might guide U.S. Army analysts in similar evaluations involving other shared maintenance facilities, particularly the forthcoming IFTE. Ultimately, the research goal is not only to support future weapon systems but also to inform logistics policy and technical decisions being considered by the Army.

RESEARCH APPROACH

This work builds directly on the conclusions and methodology of RAND's study of alternative support structures for the M1 tank. Using field repair data and computer modeling techniques, it first explores the degree of contention for the DSESTS that might be expected between the Bradley and the M1 in a priority-repair wartime environment. It then demonstrates how this integrated view of M1 and Bradley DSESTS support can serve as a framework for evaluating resource trade-offs across the two weapon systems. Using weapon-systems availability as a metric, it considers how resource investment priorities might be altered to achieve more robust and effective support structures at constant cost.

FINDINGS

In the field data analyzed here, the Bradley DSESTS workload was relatively small compared with that of the M1. The average number of DSESTS-related removals per 1,000 vehicle operating hours was more than twice as great on the M1 as on the Bradley. Removal rates of individual Line Replaceable Units (LRUs) also tended to be notably higher on the M1. As a result, the model runs examining wartime support found that theater DSESTS resources were consumed primarily by the M1. Nevertheless, the M1's availability was considerably less than that of the Bradley.

The modeling analysis provided a framework for generating and evaluating alternatives that might improve the baseline situation. Several promising options were identified:

- Significant improvement in the availabilities of *both the M1 and the Bradley* resulted when a portion of the investments in Bradley spares inventory was replaced by an equal-cost investment in (1) theater DSESTS test equipment or (2) improved theater transportation for selected high-priority items. Such test equipment or improved transport was also shown to be more *robust* than inventory in the face of uncertain rates of item demand, because their fungibility (i.e., the ability to service many types of items) helps the support system adapt to different demand mixes within and across weapon systems.
- Relocation of DSESTSs from the Forward Support Battalion (FSB) to the Main Support Battalion (MSB) resulted in substantially improved weapon-systems availabilities.

CONCLUSIONS

This study found evidence that

- The availabilities of weapon systems that share common maintenance facilities are interdependent (or "linked").
- Support policies for weapon systems linked in this way should be evaluated in terms of policy impact on total cost and effectiveness over the set of weapon systems involved.
- Such a multiple-weapon-systems analysis (1) reveals the value of resources that are *fungible across weapon systems* and (2) can help identify policies likely to yield greater weapon-systems availability from limited budgets.

ACKNOWLEDGMENTS

This research owes its original conception to Morton B. Berman, Douglas W. McIver, and Marc L. Robbins, three authors of RAND's M1 tank report. Throughout its evolution, this work has benefited from their direction and critique. RAND colleagues Raymond A. Pyles and Robert S. Tripp, in addition, provided detailed and helpful reviews of the report. I am grateful for these contributions.

Finally, I owe thanks to Karen E. Isaacson for revising Dyna-METRIC to meet the needs of this study, to Paul Steinberg for his helpful comments on the presentation of this material, and to Rosa Meza for her cheerful and efficient help in producing the report.

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GLOSSARY

AMC	Army Materiel Command
AMCCOM	Armament Munitions and Chemical Command
ASL	Authorized Stockage List
BSTF	Base Shop Test Facility
COEA	Cost and Operational Effectiveness Analysis
CONUS	Continental United States
DSESTS	Direct Support Electrical Systems Test Set
FSB	Forward Support Battalion
GS	General Support
IFTE	Integrated Family of Test Equipment
LIF	Logistics Intelligence File
LRU	Line Replaceable Unit
MSB	Main Support Battalion
NEOF	No Evidence of Failure
NRTS	Not Reparable This Station
SDC	Sample Data Collection
SLAC	Support List Allowance Computation
STE	Simplified Test Equipment
TACOM	Tank and Automotive Command
TMDE	Test, Measuring, and Diagnostic Equipment
TPS	Test Program Set
TRAC WSMR	TRADOC (Training and Doctrine Command) Analysis Command at White Sands Missile Range
UMMIPS	Uniform Materiel Movement and Issue Priority System
VISION	VIsibility of Support OptIONs
VTMR	Variance-to-Mean Ratio

I. INTRODUCTION

The U.S. Army shows signs of shifting away from using "weapon-systems-specific" test diagnostic equipment and toward using more broadly capable versions that can isolate faults within subsystems and components from a number of different weapon systems. The proposed Integrated Family of Test Equipment (IFTE), as an example, is envisioned as a single test stand that would be used to diagnose high-technology components from approximately 20 different systems, ranging from missiles to tanks and radars.

With the advent of IFTE-like facilities, the dynamics underlying weapon-systems availability take a new turn. Weapon systems that once had uncontested access to specialized test equipment will now be vying with *each other for* use *of a common facility*. As a result, their fates become linked: decisions made in support of one weapon system can affect the availability of the others. This report demonstrates the importance of taking such linkages into account when making investment and operating decisions for support resources, and it suggests a methodology for doing so.

WEAPON SYSTEMS THAT EMBODY HIGH TECHNOLOGY

Our analysis centers on two high-technology weapon systems: the M1 Abrams main battle tank and the M2/M3 Bradley Fighting Vehicle. Both the M1 and the Bradley depend on sophisticated electronic and electro-optical components to accomplish their missions. Many of these high-technology components require using the Direct Support Electrical Systems Test Set (DSESTS) to diagnose their faults in the repair process. Hence, availabilities of both the M1 and Bradley significantly depend on a shared resource: the DSESTS.[1]

This high-technology focus has its origins in a previous RAND analysis of the M1 tank, hereinafter referred to as "Berman-1988."[2] It argued that sophisticated technology in the Army's newest weapon systems presents a special challenge to the maintenance and support system. That analysis found the components of the M1's high-technology systems to be drivers of the maintenance work load, difficult to

[1]Implications of this DSESTS analysis for the IFTE are discussed in App. A.

[2]Morton B. Berman et al., *Evaluating the Combat Payoff of Alternative Logistics Structures for High-Technology Subsystems*, The RAND Corporation, R-3673-A, October 1988.

maintain, and expensive to "buy out" as inventory. Taken together, these factors highlighted the need for new approaches in supporting high-technology weapon systems, and the study demonstrated the value of alternative support structures in coping with this challenge.[3]

THE NEED FOR A MULTIPLE-WEAPON-SYSTEMS APPROACH

Whereas study of the M1 alone can sufficiently demonstrate the value of alternative support structures, failure to consider explicitly the M1's contention with the Bradley may leave other potentially important system issues and trade-offs unrecognized. As noted above, the M1 does not enjoy sole access to the support resources it needs; it must contend with the Bradley for access to DSESTS test equipment and associated personnel. (A DSESTS may be configured to test either Bradley or M1 Line Replaceable Units (LRUs). Switching between the two systems is accomplished in a few minutes by changing a diagnostic software module.) The DSESTS is critical to intermediate-level repair of many of the most sophisticated and mission-critical LRUs in the fire control and turret subsystems of both the M1 and the Bradley.

This sharing of common resources creates an interdependence between M1 and Bradley system availabilities. Test time allotted to one weapon system must necessarily come at the expense of the other. Hence, while bolstering availability of one system, the availability of the other will degrade. Less direct interactions are also present. It may be possible, for instance, to improve the availability of M1 tanks through a judicious mix of investments in Bradley spares inventory and test equipment. The richness of such interactions, and the potential to exploit them for system improvement, can be assessed by taking a multiple-weapon-systems approach.

RESEARCH GOALS

The primary goal of this research is to demonstrate the value that a multiple-weapon-systems analysis can have in helping the Army achieve more robust support structures and greater weapon-systems availability from limited budgets. Such analysis would help guide decisions on support resource investment (inventory, transportation, and

[3]Important elements of these structures included (1) moving the repair of high-technology items from the brigade-level Forward Support Battalion back to the divisional-level Main Support Battalion and (2) timely access to depot-level repair assets for selected high-technology items.

TMDE—Test, Measuring, and Diagnostic Equipment) and operation (placement of TMDE). A secondary goal is to demonstrate new techniques that U.S. Army analysts could use in similar evaluations involving other shared maintenance facilities, particularly the forthcoming IFTE.[4]

At the same time, our analysis should provide the Army with fresh insights into DSESTS support of the Bradley Fighting Vehicle and the M1 tank in wartime.

ORGANIZATION OF THIS REPORT

Section II develops a quantitative profile of the Bradley-Fighting-Vehicle DSESTS repair work load through analysis of recent field data. Section III assesses Bradley/M1 contention for the DSESTS in a dynamic wartime environment by using modeling approaches introduced in Berman-1988. In Sec. IV, we explore resource trade-offs that can be exploited to improve weapon-systems availabilities and support system robustness. Appendix A considers implications of this work for the IFTE, and App. B describes modeling input.

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[4]Whereas the shared maintenance facilities of present interest constitute automated test diagnostic equipment, the approach taken here holds lessons for the assessment of similar situations involving, for example, contention for transport and depot facilities.

II. DSESTS-RELATED REPAIR CHARACTERISTICS OF THE BRADLEY AND THE M1

Before we can examine wartime support of the Bradley and the M1, we need a quantitative assessment of the repair characteristics for these systems. This inquiry has two dimensions. First, we need to understand the *kind* of work load the Bradley generates. To what extent does it present the same kind of high-technology challenge as the M1 tank? Second, we are interested in the relative *sizes* of the M1 and Bradley DSESTS work loads, since this will largely determine the degree of contention between them.

In our analysis of these issues, we turned to the Sample Data Collection (SDC) database on repair and maintenance of Bradley Fighting Vehicles. The SDC database included data on some 300 Bradleys located in five units in the United States and Germany. (M1 information was drawn from Berman-1988 and additional SDC data on M1 repair.)

DSESTS-TESTED LRUs

Because we are analyzing contention for DSESTS resources, our primary interest is in those LRUs that require using the DSESTS for fault isolation. We dub these "DSESTS LRUs."

Table 2.1 lists the DSESTS-tested LRUs that were included in this study. Analysis of SDC data from calendar years 1984–1986 shows that the eight Bradley LRUs listed in Table 2.1 accounted for about 85 percent of the Bradley's DSESTS-related LRU removals. The remaining 15 percent are scattered across a wide range of items that were tested on the DSESTS on only a handful of occasions. Together, these eight DSESTS-tested LRUs accounted for about 19 percent of Bradley repair actions above the organizational level of maintenance (i.e., direct and general support, and depot).[1] This is comparable to the situation with the M1, where the nine major DSESTS-tested LRUs of Table 2.1 accounted for approximately 17 percent of higher-echelon repair actions.

[1]Further, three Bradley DSESTS-tested LRUs (turret distribution box, vehicle distribution box, and electronic control assembly) rank behind only the Bradley's transmission in frequency of removal for higher-echelon repair.

Table 2.1

MAJOR DSESTS-TESTED LRUs ON THE BRADLEY AND THE M1

Bradley DSESTS-Tested LRUs
Turret distribution box
Vehicle distribution box
Electronic control assembly
Power converter
Gunner's hand station
Relay assembly
Weapon control box
Turret position indicator
M1 DSESTS-Tested LRUs
Turret networks box
Computer electronics unit
Hull networks box
Line-of-sight electronics unit
Electronic control unit
Driver's instrument panel
Gun-turret-drive electronics unit
Laser range finger
Computer control panel

HOW HIGH TECHNOLOGY INFLUENCES BRADLEY SUPPORT RELATIVE TO THE M1

We now examine (1) the *kind* of work load generated by these DSESTS-tested items and (2) the implications for the support system. When considering shared electronic maintenance facilities such as the DSESTS, it is critical to recognize that the support of electronic components presents a special challenge to the Army, as evidenced by RAND's study of the M1 tank in Berman-1988. Below, we examine the Bradley in that context, juxtaposing it with the M1, to understand how sophisticated technology demands new approaches for supporting high-technology portions of these weapon systems.

Some High-Technology Characteristics of the Bradley

We note first that while the Bradley is certainly more sophisticated than its predecessor the M113, it is less sophisticated than the M1. Though both the M1 and Bradley have a similar number of DSESTS-tested LRUs, the sophistication of these LRUs and of the systems

containing them is clearly different. In the M1 tank, for example, the accuracy needed to achieve effectiveness while moving and firing a long-range heavy projectile (105mm) has resulted in an integrated system centered on a digital fire-control computer that links the system LRUs. On the other hand, the Bradley, which is still primarily a troop carrier, has a shorter gun range and lighter, 25mm projectiles that require less accuracy and tracking capability and, therefore, fewer compensations and less sophisticated fire control. Integration in the Bradley centers on its primarily electrical stabilization system for the gun and optical and thermal sights. These less sophisticated requirements in the Bradley are reflected in the lower cost of its LRUs, as seen below. Nevertheless, the Bradley does share in some degree several important high-technology-related characteristics with the M1 tank.

The Impact of High-Technology Components on Combat Capability. The combat capability of both the Bradley and M1 can be expected to degrade significantly if the high-technology components in their fire-control and stabilization systems are functioning improperly or not at all.[2]

The Need for Special Test Equipment/Personnel. The Bradley shares with the M1 and other high-technology systems a need for specialized test equipment and highly trained personnel to isolate faults within subsystems and components. Alternate troubleshooting procedures for use in absence of this equipment are often quite limited, and in any case require highly experienced personnel to execute. Hence, in this regard, repair flexibility is more limited than if simpler methods and more commonplace tools could be used.

For the M1, requisite test equipment includes the DSESTS (for 13 LRUs) and the Thermal System Test Set (for 4 LRUs), as well as organizational-level Simplified Test Equipment (the STE-M1, for which alternative troubleshooting procedures *are* well established). For the Bradley, this equipment includes the DSESTS (for 13 LRUs) and the TOW Subsystem Test Set (for 4 major LRUs, including the Integrated Sight Unit), as well as a version of the Simplified Test Equipment for organizational-level fault isolation.[3]

Difficulty of Fault Isolation. This difficulty manifests itself in the so-called No-Evidence-of-Failure (NEOF) problem: cases in which

[2]In a personal communication, Walter Clifford, Division Chief, Air Warfare Division, Army Materiel Systems Analysis Agency, estimated that if, for example, the M1 were to lose its laser range finder, it would operate with only 63 to 66 percent of its previous combat effectiveness.

[3]DSESTS capability is being expanded to cover LRUs currently tested on the TSTS, allowing the TSTS to be phased out.

LRUs are diagnosed as faulty on the vehicle and removed for repair, only to test as acceptable during further fault isolation. For Bradley DSESTS-tested LRUs in our sample, 20–30 percent of all removals were NEOFs. NEOF rates for M1 DSESTS-tested LRUs average somewhat higher, at about 44 percent, as reported in Berman-1988. To the extent that NEOFs are the result of misdiagnoses at the vehicle (rather than misdiagnoses at the DSESTS), they increase demand for DSESTSs significantly.

The Inadequacy of Spares Inventory–Buyout Solutions

The Bradley's sophisticated technology has led us to expect certain troublesome behavior from it, such as that evidenced by the NEOF problem. But one of the most fundamental implications of high-technology LRUs has proven to be the high cost associated with inventory-buyout solutions for wartime support. Were this not a problem in the Bradley, there would be a simpler way to manage M1/Bradley contention—such as, for example, removing the Bradley from the picture by simply buying out the inventory of spares.

LRU Cost. The expense of high-technology LRUs is one of their most troubling characteristics, restricting the ability to purchase spares and therefore increasing reliance on the repair system. According to the Army Master Data File, DSESTS-tested LRUs on the M1 were found to range in cost per unit from $2,364 to $22,770, with a mean of $9,681. In comparison, costs per unit for Bradley DSESTS-tested LRUs range from $329 to $18,853, with a mean of $5,053. While still not low, the cost of inventory buys for the Bradley would not tend to be as prohibitive as for the M1.

High cost, however, is only one of the difficulties in buying high-technology LRU inventory. The other is our inability to forecast demands for those items, particularly in wartime. How does the Bradley fare in this regard?

The Significance of the Variance-to-Mean Ratio (VTMR).[4] A standard approach to buying spares would rely on a well-established inventory model to calculate the amount of inventory needed to cover expected demands in the future. Such models are typically based on the assumption that the VTMR of LRU removals equals 1. However, estimates of VTMRs for a wide range of LRUs have typically run

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[4]We note that, in fact, the VTMR concept as applied in this report is probably a proxy for unpredictable changes in the mean and/or variance of the removal distribution. In the absence of a stable distribution, these high VTMRs serve to describe the data that result from this volatility in the distribution itself.

higher.[5] Our analysis of the M1 tank showed its high-technology components to be no exception to this pattern (see Berman-1988). In theory, higher VTMRs indicate wider swings in demand (relative to the mean) than would be the case if VTMRs were equal to 1. When VTMRs are relatively low, demands tend to hover more closely around the mean. In such cases, we must buy only a relatively small amount over the mean to cover peak demand points. As VTMRs rise, however, demand at any given time is more likely to greatly exceed the mean. Under these conditions, we will have to buy further above the mean if we wish to cover against these swings in demand.

VTMRs in Peacetime and Wartime. Table 2.2 shows that VTMRs for Bradley DSESTS-tested LRUs, as estimated from peacetime data, are also greater than 1. In fact, demand variability of

Table 2.2

VARIANCE-TO-MEAN RATIOS FOR DSESTS-TESTED LRUs[a]

Bradley LRUs	VTMR
Turret position indicator	3.2
Electronic control assembly	2.9
Power converter	2.0
Turret distribution box	1.9
Weapon control box	1.9
Vehicle distribution box	1.8
Gunner's hand station	1.5
Relay assembly	1.5
M1 LRUs	**VTMR**
Turret networks box	2.9
Laser range finger	1.9
Line-of-sight electronics unit	1.8
Driver's instrument panel	1.7
Electronic control unit	1.2
Gun turret drive	1.2
Hull networks box	1.0
Computer electronics unit	0.89
Computer control panel	0.86

[a]Bradley data from 1984–1986; M1 data from 1985 (as in Berman-1988).

[5]Gordon B. Crawford, *Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications*, The RAND Corporation, R-3318-AF, January 1988.

Bradley DSESTS-tested LRUs appears to be at least as great as that for M1 DSESTS-tested LRUs, if not greater. Such VTMRs raise the price of inventory purchases intended to cover against swings in demand. Moreover, these estimates are based on peacetime operating tempos; any inventory purchasing intended to protect against shortages in wartime must also take into account the effect of the higher operating tempos expected then. Berman-1988 estimated that at wartimelike tempos VTMRs can easily be three times those generally seen in peacetime. (That estimate was derived from an analysis of VTMRs for a sample of M1 tanks with unusually high peacetime tempos.)

To be protected from swings in wartime demand, then, we would need to base our inventory calculations on high-tempo VTMRs rather than on the standard VTMR = 1 assumption. Figure 2.1 illustrates the dramatic effect that high-tempo VTMRs (three times larger than the VTMRs of Table 2.2, consistent with Berman-1988) can have on inventory-purchase requirements, even for the small number of

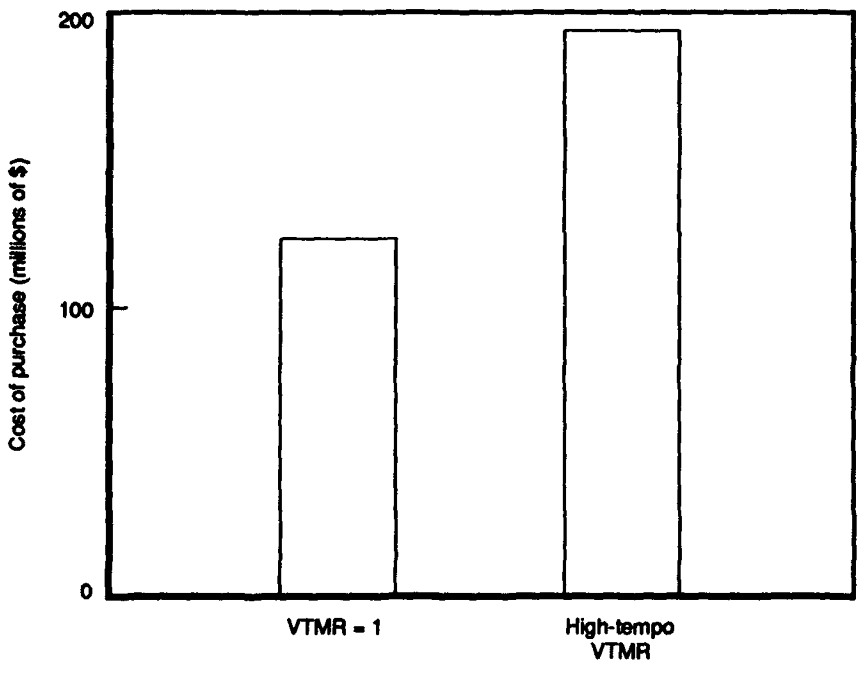

Fig. 2.1—Influence of VTMR on spares inventory purchase required to maintain 80 percent M1 and Bradley availabilities

DSESTS-tested LRUs considered here. The figure reflects the cost of purchasing enough DSESTS-tested LRUs to maintain a corps of 928 M1s and 1,056 Bradleys at 80 percent availability over a 120-day wartime scenario (i.e., availability *due to DSESTS-tested LRUs*). This purchase is not in lieu of existing DSESTS repair capability but rather is the amount required to supplement that capability in the base case we will see in Sec. III.[6]

Additional Variability. Even this picture, though, is not complete. Unfortunately, even if one decided to "pay the price" and buy as much inventory as indicated by using the "correct" wartime VTMRs, one would still not be assured of safe coverage. VTMRs on both the M1 and the Bradley typically change from year to year. (VTMRs on the Bradley's electronic control assembly were 1.6, 4.0, and 3.3 in 1984, 1985, and 1986, respectively.) Inventory purchases based on current VTMRs, then, cannot ensure against shortages (since demands may still be higher than forecast) and can entail wasteful spending in the attempt to do so (since demands may be much lower than forecast).

Finally, and perhaps most important, even if we could predict wartime *VTMRs*, they alone could not capture wartime *variability*. The nature of combat will be a source of tremendous variability that is quite distinct from questions of statistical methodology. In the face of an unknown future threat, there is a great deal of uncertainty even about the average operating tempos we can expect to face. Further complicating the matter will be the unpredictable behavior of weapon systems being stressed in new modes and in inhospitable physical environments. Combat damage to LRUs and to the support structure itself (stocks, repair facilities, etc.) may play a significant role as well. These largely unforeseeable situations, combined with the high cost of high-technology LRUs, discourage hopes of assuring weapon-systems availability through the purchase of an "adequate" number of spares.

COMPARING THE RELATIVE SIZES OF BRADLEY AND M1 DSESTS WORK LOADS

Bradley DSESTS-tested LRUs, then, exhibit demand variability very similar to those of the M1 and other high-technology systems.

[6]These purchases are calculated at 90 percent confidence, using the base case of our Dyna-METRIC model, which is explained in more detail in the next section and in App. B. The actual cost estimates are considerably sensitive to Dyna-METRIC assumptions and inputs. The relative difference seen here, however, is characteristic of a wide range of cases and tends to be even more pronounced as the number of LRUs considered grows.

These LRUs appear in general to pose problems similar in *kind* to those on the M1 tank, though less pronounced in terms of cost and technological sophistication.

We now move more directly to the contention issue with an assessment of the relative *size* of DSESTS work loads on the M1 and the Bradley. In Berman-1988, RAND's previous study of the M1 tank, the Bradley work load was accounted for in a nominal way. Half of the corps DSESTSs were allocated to M1 repair, and the other half were assumed to support the Bradley. The implicit supposition was that the Bradley and the M1 generate roughly equal DSESTS work loads. Our analysis of the Bradley SDC data now allows us to address this assumption directly.

We have seen that the Bradley and the M1 have about the same number of major DSESTS-tested LRUs. But as Table 2.3 shows, the rate of removal of those LRUs over a three-year period was more than twice as great on the M1. Comparison of removal rates based on equal use (1,000 hours) is of course misleading if we expect total Bradley wartime use to differ markedly from M1 wartime use. However, as the next section shows, the best evidence does in fact suggest roughly equivalent use in wartime, arising from a nearly equal number of Bradleys and M1s operating at approximately equivalent mean tempos. Hence, the dominance of M1 demands shown in Table 2.3 holds. This is an important result in light of the "roughly equal work loads" hypothesis.[7]

Demand for Repair on the Bradley in Wartime

To model wartime support of the M1 and the Bradley, we required a host of estimates, the most important of which is the frequency with which LRUs will be removed for repair (apart from battle-damaged LRUs that cannot be repaired). This is not a well-understood variable, since peacetime data can seldom give insight into the manner and conditions of operation likely to be encountered in wartime. Although we cannot expect to estimate *actual* removal rates, we do attempt to capture the removal rates of the Bradley *relative* to the M1.

Berman-1988, the previous RAND study of the M1 tank, turned up strong evidence that the number of LRU removals increases linearly

[7]Estimates derived from more limited data also place average M1 repair times somewhat higher than those of the Bradley, about 4.8 M1 hours to 2.8 Bradley hours (weighted by frequency of removal). We suspect, however, that the M1 data estimates include some off-stand repair time as well. We have accepted these higher M1 figures as conservative estimates and have used them in the computer runs noted in the following sections. This assumption does not bias the study outcome.

Table 2.3

REMOVAL RATES OF MAJOR DSESTS-TESTED LRUs[a]

Bradley LRUs	Removals per 1,000 Hours
Turret distribution box	1.00
Vehicle distribution box	0.75
Electronic control assembly	0.72
Power converter	0.23
Gunner's hand station	0.22
Relay assembly	0.22
Weapon control box	0.16
Turret position indicator	0.14
Total	3.44
M1 LRUs	**Removals per 1,000 Hours**
Turret networks box	1.80
Hull networks box	1.20
Electronic control unit	1.00
Driver's instrument panel	0.92
Computer electronics unit	0.83
Gun-turret-drive electronics unit	0.75
Laser range finger	0.70
Line-of-sight electronics unit	0.62
Computer control panel	0.14
Total	7.96

[a]Removal rates are given in terms of the average number of removals requiring DSESTS testing per 1,000 vehicle operating hours. Bradley data from 1984–1986; M1 data from 1985–1987.

with vehicle operating hours. Analysis of Bradley data indicates the same to be the case for Bradley DSESTS-tested LRUs. However, neither analysis had data in the region of estimated wartime tempos. This study makes the standard assumption, therefore, consistent with Berman-1988, that removal rates of DSESTS-tested LRUs (removals per 1,000 hours) at wartime tempos are equivalent to those in peacetime.

III. EVALUATING WARTIME SUPPORT OF MULTIPLE WEAPON SYSTEMS

Our goal in this section is to better understand the current baseline situation for combined M1/Bradley DSESTS support in wartime. This analysis should be of value insofar as it offers Army support planners a view of the active contention that arises between the two weapon systems. It also serves as a springboard for the formulation of more effective support alternatives, as presented in Sec. IV.

THE MODEL

Our view of the logistics system follows that of Berman-1988, which emphasizes a "systems view" encompassing removals, failures, test equipment, repair, transportation, and the uncertainties and interdependencies among them.

Using the Dyna-METRIC model, we measured the contention for the DSESTS in terms of its implications for M1 and Bradley availability. Dyna-METRIC has been developed at RAND over the last ten years and has been used extensively by the Air Force to conduct sustainability assessments.[1] More recently, it has been used to evaluate alternative support structures for Army high-technology weapon systems. It is capable of accounting for the integrated effects of transportation, supply, maintenance, and situational visibility on the availability of weapon systems.[2]

MODEL INPUTS

Our aim is to evaluate M1 and Bradley support in a wartime environment. Consequently, besides requiring historical data on the

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[1]Dyna-METRIC has been embedded in the Air Force Weapon System Management Information System (WSMIS). WSMIS provides weekly assessments to Air Force wing commanders and is reported in the Air Force Unit Readiness Reporting System. For more information on WSMIS, see *WSMIS Sustainability Assessment Module (SAM), Functional Description* (Version 8.0), Dynamics Research Corporation, Andover, Mass. 01810.

[2]Karen Isaacson, Patricia M. Boren, Christopher L. Tsai, and Raymond A. Pyles, *Dyna-METRIC Version 4: Modeling Worldwide Logistics Support of Aircraft Components*, The RAND Corporation, R-3389-AF, May 1988.

maintenance and repair process (removal rates and VTMRs, repair times, Not Reparable This Station (NRTS) rates, etc.), we also need (1) to define a force structure and an operational scenario, and (2) data on test equipment availability, transportation, damage to assets, and spares inventories.

This analysis employs an operational scenario that assumes a large-scale conflict between NATO and the Warsaw Pact in Central Europe. Since the analysis was completed, events in Europe appear to have dramatically decreased the likelihood of such a conflict. It is perhaps important, therefore, to emphasize that we believe the *support principles* that are focused on here—such as coping with uncertainty by emphasizing responsive and robust support resources—will be at least as critical in the future. Indeed, given the increased uncertainties regarding even such "fundamentals" as force structure and location of theater, such support principles may prove even more vital.

Appendix B catalogs the input in more detail. In brief, we model a corps made up of one armored division and two mechanized divisions, for a total of 928 M1s and 1,056 Bradleys (756 M2s and 300 M3s). A review of operating-tempo data obtained from the U.S. Army Logistics Center showed projected operating hours for tanks and fighting vehicles to be essentially the same (except for the M3 in cavalry squadrons). In our model, these ranged from 7.7 hours per day in a light defense/static posture to 15.1 hours per day for full offense.

KEY ASSUMPTIONS

Logistics Structure

The logistics structure of this three-division corps is standard Army form. (See Fig. 3.1 for an abbreviated structure diagram.) Each brigade has an FSB (Forward Support Battalion), and each division possesses an MSB (Main Support Battalion). The three divisions are in turn linked through a Corps Support Command to a depot in the Continental United States (CONUS). In the base case, repair of LRUs takes place at the FSBs, each of which has two DSESTSs.[3] Queues there are limited to two-days' work load, however, and excess items are

[3]Inclusion of additional repair capacity at the General Support (GS) level would somewhat increase the availabilities seen in this analysis. We do not believe that it would alter the fundamental *balance* of contention, however, nor the trade-offs examined in the next section.

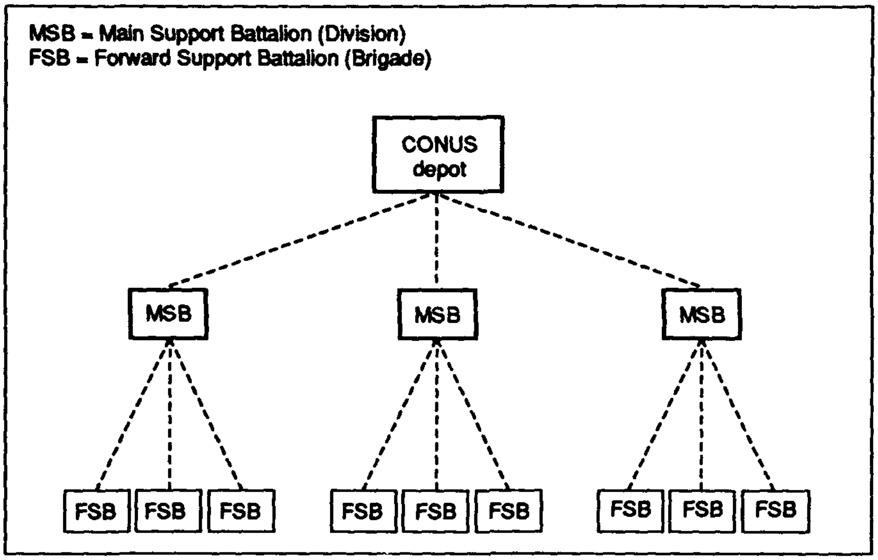

Fig. 3.1—Logistics structure of the scenario

then "overflowed" back to a depot for repair.[4] In addition, some percentage of all LRUs are unable to be repaired in the theater. These are declared NRTS and are also sent back to the depot for repair. We do not model depot capabilities in detail here, but consistent with Berman-1988 we assume that depots are of sufficient capacity to process LRUs through administrative and repair delays in 10 days. We also assume unit-to-depot transport times of 28 days retrograde and 21 days forward, with retrograde beginning only after the first 30 days because of the need to devote transportation assets to unit movement early in the war.[5] (See App. B for further information.) LRU stock is assumed to be placed in the theater, and hence availability of spare parts is unaffected by this cutoff.

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[4]This makes the model roughly consistent with the 36-hours FM-43-12 *Guidelines*, Division Maintenance Operations, April 1986.

[5]The Army's program office for TMDE notes that these transport times might be considered optimistically short. Use of longer times would leave the first 90 days of the availability curves presented here unchanged, because depot-repaired items do not begin returning into theater until that time. The upturn in availability seen at the 90-day point, however, would not be seen until later in the war, in accordance with the longer transport times.

Battle Damage to Test Equipment

All cases in this analysis include modeling of battle damage to the DSESTS, using estimates consistent with Berman-1988. The probability of damage to each DSESTS from enemy artillery fire ranged from 0.25 percent to 3.5 percent per day at the FSB, varying with the intensity of battle. For cases with repair at the MSB, probability of damage remained constant at 0.25 percent. Once damaged, a DSESTS remained inoperable for 30 days, at which time repair/replacement was assumed to have been completed.

Priority Repair Policy for M1/Bradley

Dyna-METRIC allows us to model priority repair, dynamically choosing to focus next on those LRUs whose repair will most improve weapon-systems availability. Under assumptions of controlled substitution (which minimizes the number of disabled vehicles by consolidating "holes" onto the fewest vehicles possible), this amounts to repairing the LRU that has the largest back order. Hence, determining priority among LRUs from a particular weapon system is straightforward. But which weapon system should be given priority? Should we repair a Bradley part next, or an M1? The Army will be increasingly challenged to make such choices as IFTE-like environments develop and will need to form criteria upon which to base these choices.

In this analysis, we chose to direct repair toward preserving the same balance of M1s and Bradleys with which our corps began. In the case at hand, this simply translates to keeping an approximately equal number of Bradleys and M1s mission-capable in the field. To meet this goal, each unit in our model allocates repair so as to maintain the M1/Bradley ratio in that unit. Hence, at an FSB supporting 100 M1s and 50 Bradleys, Bradleys would receive twice the weight of M1s when determining priority. With each unit maintaining its own M1/Bradley ratio, the corps as a whole will also maintain its initial M1/Bradley ratio. This seems a reasonable *average* goal from the perspective of the corps as a whole, assuming that the initial force structure is indicative of operational combat needs.

In practice, however, operational combat needs are likely to be highly situational, and we believe repair schemes that are more situationally *responsive* than the one employed here can have high combat payoff. Efforts should be made, for example, to keep repair sensitive to ongoing mission needs, which would vary as the war progressed and which could vary widely from unit to unit. In doing so, trade-offs would likely arise between the unit's combat needs (e.g., as many tanks

as possible in the next two days) and the mix of weapon systems the support system can deliver if it works expediently (e.g., 20 tanks in the next two days, or 15 tanks and 10 Bradleys).

Although such detail is beyond the scope of this present analysis, in other work we are developing prototype management and decision support systems capable of implementing such repair goals in a coordinated fashion across echelons, and we are assessing the payoffs of such systems for combat capability using more advanced versions of Dyna-METRIC.[6] We therefore consider the priority scheme of the present analysis to represent a kind of minimal rudimentary capability for the support of multiple weapon systems. Nevertheless, it is important to point out that even this scheme requires an appropriately oriented management system.

CONTENTION FOR THE DSESTS IN WARTIME

Influence of Contention on Weapon-Systems Availabilities

We can best begin to examine contention for the DSESTS by establishing a base case that focuses on the M1 alone. This case replicates the base case from Berman-1988 that includes battle damage to the DSESTS. The support system is configured according to current Army doctrine, with LRU repair taking place at the FSB. One DSESTS at each FSB is available for M1 repair, with the other DSESTSs assumed devoted to Bradley repair, under the hypothesis of equal work loads. Figure 3.2 shows the expected percentage of M1 tanks having a fully mission-capable suite of DSESTS-tested LRUs over the 120-day scenario for this case. (In other words, the figure shows the availability of M1 tanks due to DSESTS-tested LRUs.) Hence, while availability of the overall system may be even less because of problems with other LRUs, it will not be more. (The sudden upturn in availability at day 90 is a result of certain items—those that had been sent back to a depot as overflow or because they were declared NRTS—finally beginning to return to the theater after the initial 30-day cutoff and subsequent 59-day unit-to-depot-and-back turnaround time.)

We next incorporate repair demands of both the Bradley Fighting Vehicle (BFV) and the M1. To emphasize contention, however, we momentarily hold the number of available DSESTSs to 9 (1 at each

[6]For an introduction to this research, see Robert S. Tripp, Morton B. Berman, and Christopher L. Tsai, *The Concept of Operations for a U.S. Army Combat-Oriented Logistics Execution System with VISION (VIsibility of Support OptIONs)*, The RAND Corporation, R-3702-A, March 1990.

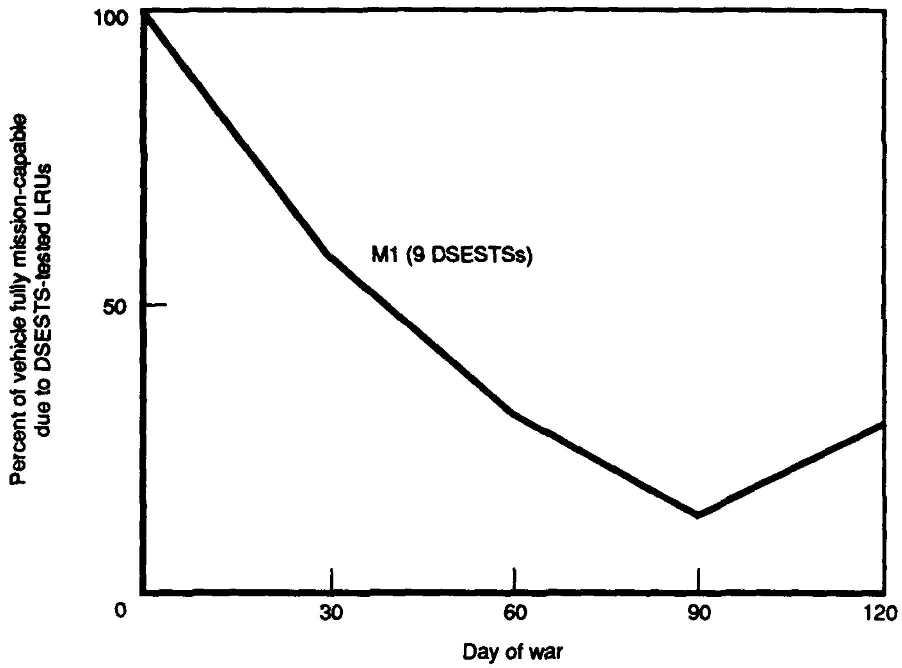

Fig. 3.2—Mean wartime availability of the M1 due to DSESTS-tested LRUs, using 9 DSESTSs

FSB). Dyna-METRIC dynamically allocates DSESTSs according to the priority repair policy that seeks to keep an equal number of each weapon system mission-capable. Under the "DSESTS equal workloads" hypothesis, we would have expected to see M1 availability deteriorate considerably with the addition of the Bradley because of the diversion of DSESTS resources to Bradley repair. However, our analysis of field data has indicated that the M1 work load may dwarf that from the Bradley. Figure 3.3 bears out the effects of this disparity. In it we see that adding the Bradley leaves M1 availability essentially unaffected.

This occurs because M1 LRUs are removed much more frequently than Bradley LRUs and because the Bradley is better stocked in spares. (See App. B for spares inventory levels.) Hence, the bulk of DSESTS resources is devoted to M1 repair in an effort to keep M1 availability competitive with the Bradley. Even so, the M1 lags behind. With M1 LRUs taking priority, virtually all Bradley LRUs

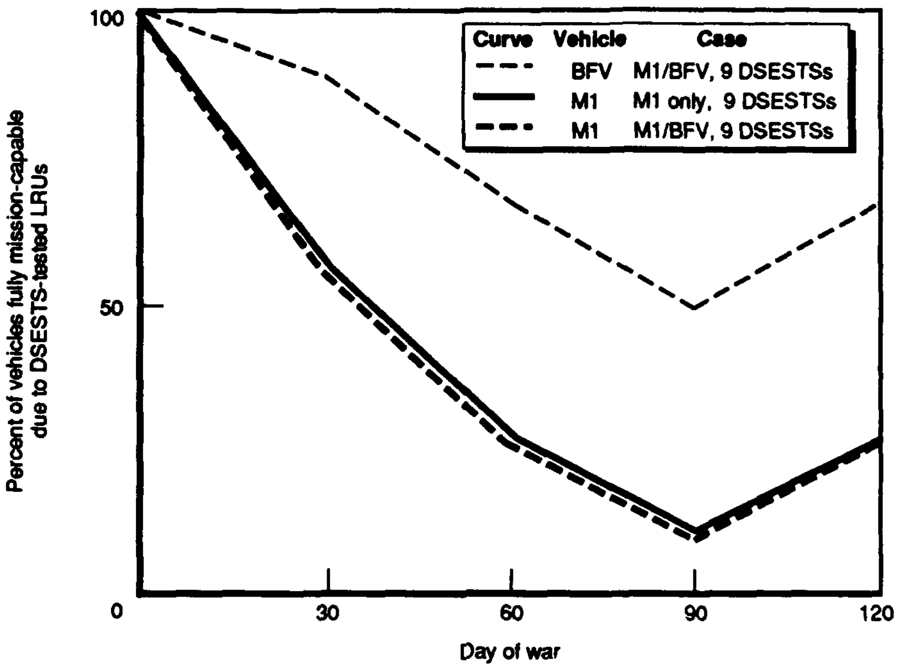

Fig. 3.3—Mean wartime availability of M1/BFV due to DSESTS-tested LRUs, using 9 DSESTSs

overflow back to the depot for repair. However, with the rate of removals on the Bradley so light and stockage available to help replace a portion of them, even the long delay in depot turnaround (59 days plus initial 30-day cutoff) does not cause Bradley availability to become worse than the M1's.

Finally, we consider the full case: M1 and Bradley repair with all 18 DSESTSs available (two at each of nine FSBs). DSESTS access is again allocated according to the priority repair scheme, with the result that approximately 70 percent of the new test capacity that had been held in reserve for the Bradley is actually devoted instead to the M1. Even so, as Fig. 3.4 shows, M1 availability continues to lag behind the Bradley. This analysis, then, indicates that the Bradley actually has very modest needs *relative to the M1*.

A closer look at these results also suggests that the location of repair at the FSB can hamper the support system's effectiveness. First, Fig. 3.4 demonstrates how dispersion of test equipment to the FSBs limits

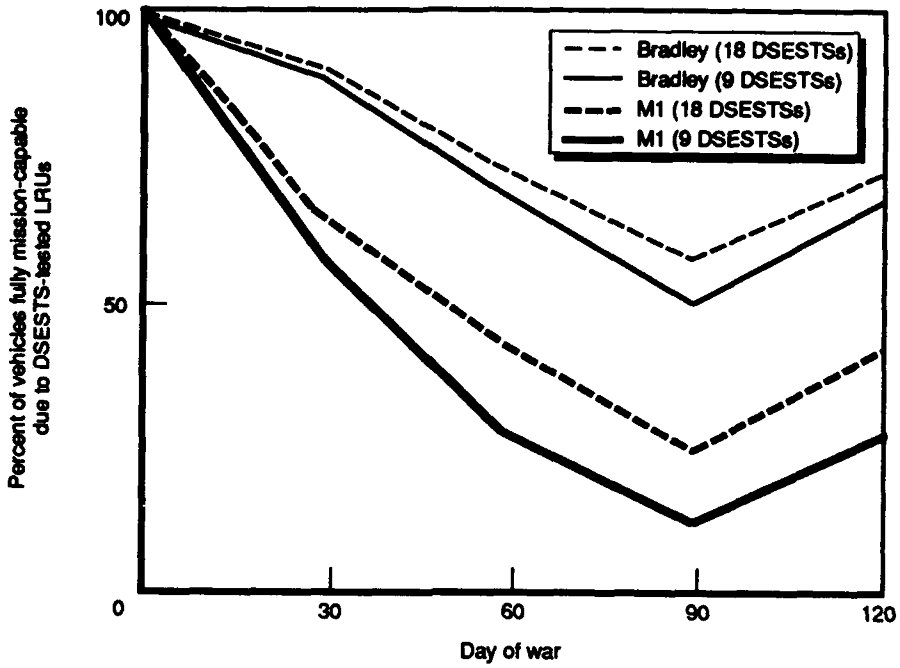

Fig. 3.4—Mean wartime availability of M1/BFV due to DSESTS-tested LRUs, comparing 9 and 18 DSESTSs

the ability to focus resources on the weapon system of choice. Because availability of the M1 is so much lower than that of the Bradley in the 9-DSESTSs case, we would expect priority repair to allocate 100 percent of any additional DSESTS capacity to the M1 until the M1 is brought roughly equal to the Bradley. When DSESTSs are doubled from 9 to 18, however, 30 percent of that new test capacity is allocated to the Bradley, resulting in the rise in Bradley availability seen in Fig. 3.4. This is primarily because at very Bradley-heavy brigades, the M1 work load is small, and remaining test capacity is therefore directed to the Bradleys in those brigades—even though there are large backlogs of M1 work at other brigades.[7] Hence, dispersion of test equipment limits

[7]Some lesser factors also prevent the attainment of equivalent M1/Bradley availabilities here. When a brigade's test equipment is unavailable, the M1's higher removal rates generally cause its availability to degrade more rapidly than the Bradley's. Because these items are overflowed into the depot pipeline, the imbalance cannot be recovered later when test equipment is available again. (Even if items were backlogged at the FSB, test equipment is needed merely to keep pace with daily demands.)

the ability to focus resources on the needs of the divisions, or the corps, as a whole.

A second, more dominant drawback to FSB-based repair is reflected in the fact that doubling the number of DSESTSs from 9 to 18 only modestly improves availabilities. At the FSB, the need for frequent movement and the incidence of DSESTS damage (caused by proximity to the battle) seriously reduce the availability of the test sets and, thus, limit the number of items that can be processed. As the next section will demonstrate, weapon-systems availability can benefit substantially from DSESTS relocation to the MSB.

SENSITIVITY OF RESULTS

The central finding in this section has been that the Bradley actually has very modest needs for DSESTS resources *relative to the M1*. Having already emphasized the uncertainties rampant in projecting wartime operations, however, it is reasonable to ask whether this result is a mere artifact of model inputs and assumptions or whether it might represent something more. Certainly the availability curves will change significantly under different assumptions for operating tempos, removal rates, test equipment availability, repair times, spares inventory levels, etc. The real question is whether the relative statuses of the M1 and the Bradley are equally as fragile. We must first identify the driving factors causing that result and then judge how stable a basis they provide.

Importance of Removal Rates and Spares Inventory Levels

The M1's dominance of theater DSESTS resources in this analysis appears to be powered primarily by the disparity between M1 and Bradley removal rates. While we have seen that the *total number* of M1 removals is more than twice as great as the Bradley's per unit of time, a more critical factor in general is how those removals are distributed among various LRUs. From a repair-priority viewpoint, resources must be directed to those LRUs disabling the greatest number of vehicles. Hence, even with a smaller overall removal volume, the Bradley could have significant impact on M1 availability if those removals were concentrated in a few LRUs. Those LRUs could then be first choice for DSESTS testing. However, as Fig. 3.5 illustrates, the most frequently removed LRUs belong largely to the M1.

Factors other than removal rates also contribute to an LRU's bearing on M1/Bradley availability. High removal rates can be ameliorated

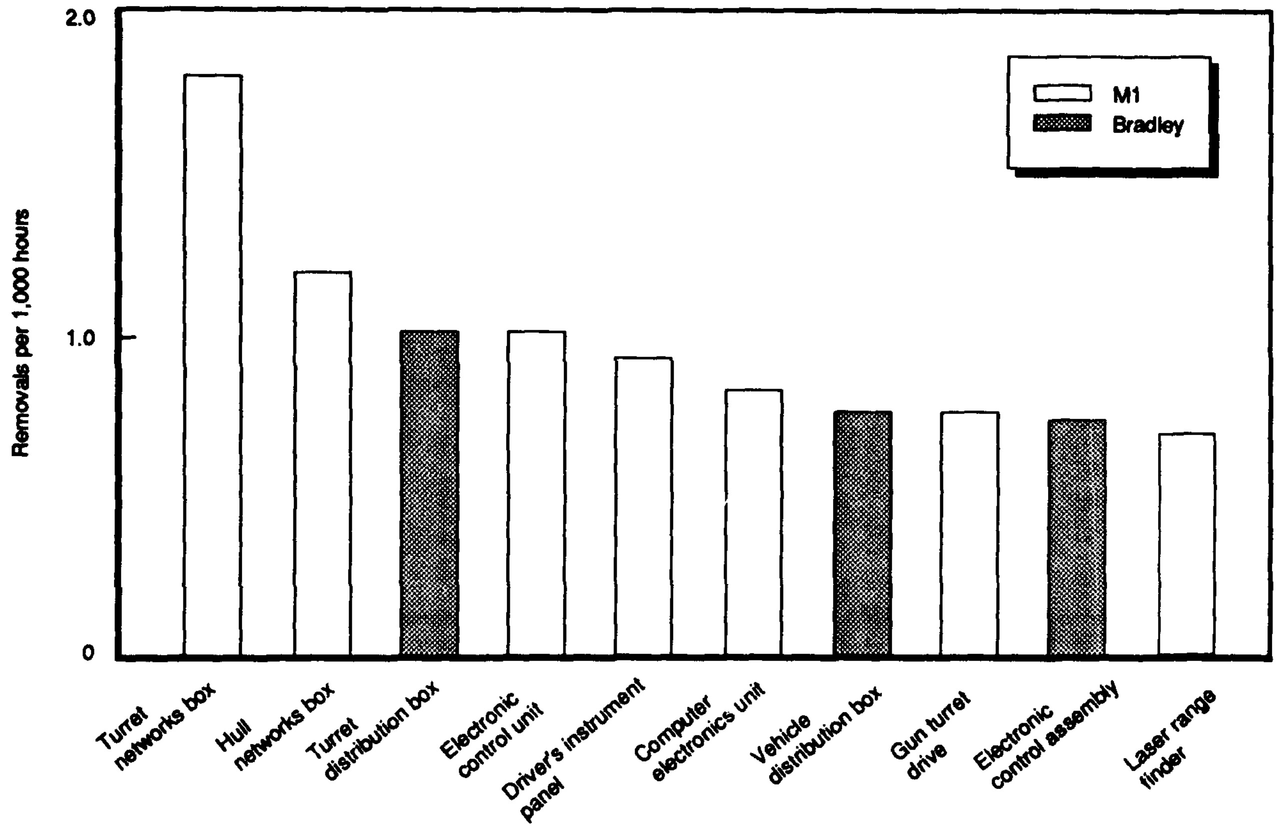

Fig. 3.5—Removal rates of M1 and Bradley DSESTS-tested LRUs

through high inventory levels, and an LRU with a relatively low removal rate could become quite a problem if its NRTS rate is high. In the present case, the depth of Bradley inventory relative to that of the M1 is another sizable factor in the Bradley's favor. Because of this advantage in spares inventory, Bradley LRUs tend to rank even lower in the priority system than Fig. 3.5 alone would suggest.

We now consider sensitivity to removal rates and inventory levels, each in turn.

Sensitivity to Removal Rates

Prediction of wartime removal rates is one of the most unworkable problems in this area. How useful then is a result predicated on such rates? Actually, the result is predicated on a major disparity in removal rates rather than on the removal rates themselves. Hence, to offset our results, a sizable relative shift in our estimates of the mean removal rates would have to take place.

Sensitivity analysis indicates that Bradley removal rates would need to be roughly double those estimated here (i.e., nearly equaling the M1) before the Bradley can become a serious contender for DSESTSs relative to the M1. Although Bradley availability naturally degrades as its removal rates increase, that degradation is not serious enough to divert a significant portion of DSESTSs away from the M1 until those rates nearly double.[8] Note that this refers to a shift in the mean total removal rate on the Bradley sustained over the duration of the war, not a temporary shift because of demand variability. In the context of the historical *peacetime* data analyzed in the last section, this shift would be quite sizable, because the total removal rate (over a given year) for M1 LRUs consistently overshadowed that for the Bradley by a ratio of at least 1.7 and as much as 3.0. Removal rates for M1 "high drivers" (those LRUs most frequently removed) were also generally about twice those for Bradley "high drivers." Forecasters should be wary of drawing *too much* comfort from this peacetime data, however, because under the stresses and environmental conditions of wartime, large shifts in removal rates are not uncommon, at least for individual LRUs or for groups of related LRUs.

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[8]The shorter test times associated with Bradley items mean that even as their removal rates approach those of the M1, the Bradley still needs much less DSESTS capacity than the M1 does.

Sensitivity to Spares Inventory Levels

Granting reasonable availability of repair facilities, as we have here, spares inventory levels appear to play an important but secondary role (behind removal rates) in driving our results. We can remove virtually all Bradley spares and yet barely affect M1 availability (though Bradley availability does degrade somewhat). As we will see shortly, this may suggest trade-offs for the Army to consider in its plans for inventory investments.

Sensitivity to Operational and Other Assumptions

The dominance of the M1 over the Bradley in the contention for DSESTS resources appears to be reasonably robust, with large perturbations in removal rates or spares inventory level required to begin to alter the balance. It is important to note, however, that this result is nevertheless conditioned on other key assumptions, which include the following:

- Roughly equal overall use of Bradleys and M1s (arising from approximate equality in vehicle count and operating tempo).
- The goal of keeping a roughly equal number of Bradleys and M1s mission-capable, which essentially grants each system equal weight in repair priority (averaged over the corps as a whole).
- Adequate number of "float" M1s and Bradleys to replace vehicles lost to catastrophic kills.

Marked deviations from these standards could change the Bradley's competitive status. (For instance, a shortage of floats would tend to reduce the load on the maintenance system, and relatively more severe shortages for the M1 could selectively lighten the M1's work load relative to the Bradley's.) Even so, however, such deviations would probably need to be relatively large to offset the removal-rate and spares inventory disparities.

IMPLICATIONS FOR RESOURCE INVESTMENT

This analysis has implications for resource investment planning, suggesting, for instance, that advantageous trade-offs might exist between Bradley spares inventory and other support resources. Moreover, it provides us with a tool for exploring those trade-offs and for

identifying alternative investments that might generate higher weapon-systems availability at constant cost. In the next section, we turn to this task.

IV. EXPLOITING RESOURCE TRADE-OFFS ACROSS WEAPON SYSTEMS

The goal of shared maintenance facilities—whether DSESTS, IFTE, or transportation—is to help achieve high availability for the weapon systems they serve. But for each of those weapon systems there are other routes to high availability (purchase of spares, etc.). In deciding how to distribute investments among these different routes, we must take into account not only the effect on the weapon system of interest, but also the effect on other weapon systems to which it is linked through the shared facility.

Ideally, this can help the Army achieve more effectiveness from limited budgets by identifying investments that benefit as many of the weapon systems involved as possible. At a minimum, such analysis can help ensure that decisions made in support of one weapon system do not inadvertently compromise the availability of others.

ALTERNATIVE INVESTMENT PRIORITIES FOR M1/BRADLEY DSESTS SUPPORT

The M1/Bradley case provides a brief example of this kind of analysis. As App. B illustrates, full purchase of Bradley war reserve and the Authorized Stockage List (ASL) would leave the Bradley fairly well stocked relative to the M1. We might question whether that expenditure is the most advantageous or whether an equivalent investment elsewhere might provide a higher payoff in terms of robustness and in terms of M1 and Bradley availabilities. In particular, the Army might consider planning for alternative investments in the following areas:

- Additional theater DSESTS equipment and personnel, the potential value of which is self-evident.
- Improved theater transportation of LRUs en route to depots for repair. Berman-1988 showed that providing assured priority transportation for selected LRUs (by adding a Blackhawk helicopter in the theater and appropriate management systems) could significantly improve weapon-systems availability at rela-

tively low cost.[1] By reducing in-theater transfers for high-priority items, such a move might reasonably reduce their baseline depot turnaround time of 60 days to about 24 days, according to Berman-1988. We use this same factor in the assessment that follows.

Both these alternatives offer the critical feature of *fungibility* (i.e., the ability to service many types of items). DSESTSs placed in the theater can service the full range of DSESTS-testable LRUs on both the Bradley and the M1. Improved transport can likewise service DSESTS-testable LRUs that must overflow back to a depot and can further expedite the turnaround of NRTS items (that cannot be repaired in the theater at all). Backed by appropriate management and decision support systems, these fungible resources can be directed toward the particular priorities at hand.[2] This starkly contrasts with inventory purchases; for instance, once Bradley ECAs (electronic control assemblies) are purchased, they cannot be adapted to priority needs for other items that may arise. The need for fungibility increases greatly as the uncertainties in item demand, discussed earlier, cumulate across many LRUs and several weapon systems.

The benefits of these fungible resources, of course, must be weighed against their cost and against the need for each resource in the system as modeled. A very high percentage of NRTS cases, for instance, would skew the decision toward improving transport. The baseline location and number of DSESTSs will affect the marginal utility gained from adding more of them, and so on. A dynamic model of the support system such as we have developed here can help in assessing these factors in an integrated fashion.

SAMPLE EVALUATIONS OF ALTERNATIVE INVESTMENT PRIORITIES

Increased Emphasis on Test Equipment

Figure 4.1 compares performance of the current M1/Bradley DSESTS support system with one that places greater emphasis on

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[1]Berman-1988 estimates the cost of an additional Blackhawk at $11.9 million, which includes procurement, operation and support, additional maintenance personnel and aircrews, and initial training costs for aircrew members over a 20-year life cycle.

[2]Management and decision support systems are not considered an alternative investment because the assumed priority scheme is rather basic; it would not necessarily entail additional investment, though it would entail the "reorientation" of existing resources and procedures. The specifics of such reorientation are being addressed in the VISION study, which is also examining the costs and benefits associated with more advanced management systems.

DSESTSs and less on Bradley spares inventory. This new case essentially redirects \$12 million worth of Bradley spares toward the purchase of 10 additional DSESTSs (for a total of 28 DSESTSs).[3] Despite the fact that the effect of these DSESTSs is diluted by field movement and battle damage, we see both a slight increase in Bradley availability and a significant rise in the availability of the M1.

A closer look reveals what has happened. In Fig. 4.2a, we see the portion of Bradley inventory that was exchanged for additional DSESTSs. (Many variations on this profile are possible.) This investment in spares could satisfy a total of 1,254 demands, but it can only satisfy demands for the particular Bradley LRUs shown and is limited

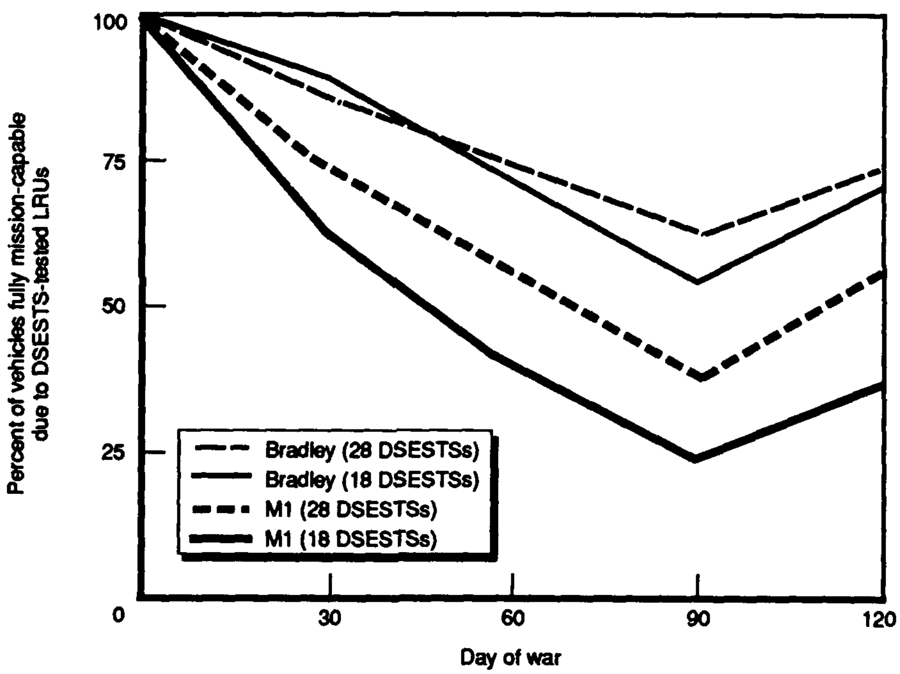

Fig. 4.1—Mean wartime availability of M1/BFV, exchanging Bradley spares inventory for 10 more DSESTSs

[3] Berman-1988 estimates the cost of a DSESTS at about \$1.2 million, including the test set, procurement of the van that houses and transports it, operation and support of the van, and two DSESTS maintainers, over a 20-year life cycle. This cost is computed by multiplying annual costs by 10, based on an assumed 7.75 percent discount rate. Similarly, a present value factor of three is used when dealing with the assumed five-crew-member turnover during the 20-year life cycle.

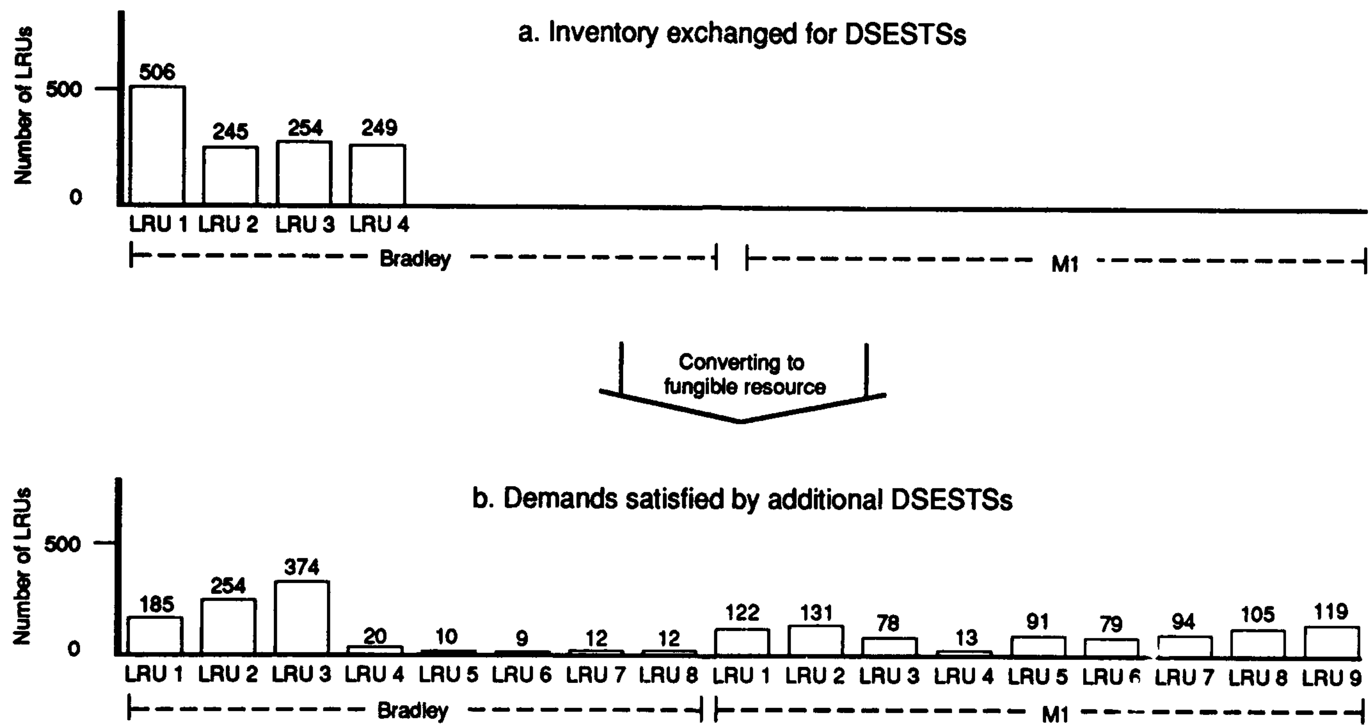

Fig. 4.2—Converting to a more fungible resource

to the quantities indicated. In fact, in the base case, these spares were not even all used. Converting this investment into DSESTSs results not only in a larger number of demands being satisfied overall (1,708), but more important, it enables the system to focus on those LRUs in most urgent demand in the scenario at hand. As Fig. 4.2b shows, this includes a significant amount of repair across a range of M1 LRUs and sufficient attention as well to the Bradley LRUs that most improve its availability (even though the total number of Bradley demands satisfied was less than in the base case).

DSESTSs therefore proved to be a more cost-effective investment than did inventory in this analysis, yielding greater weapon-systems availability at equal cost. It is important that this analysis also demonstrates how the DSESTS can be a more robust investment as well, because its *fungibility enables the support system to adapt to a range of different demand mixes, both within and across weapon systems.*[4] Such robustness is evident even with the rudimentary representation of priority repair used here, and we believe that even more significant payoffs will be found through our ongoing management system work that focuses specifically on the achievement of more broadly responsive and robust support.

Increased Emphasis on Theater Transportation

Alternatively, we might keep the baseline number of 18 DSESTSs and instead redirect $12 million in Bradley spares inventory toward purchasing a Blackhawk helicopter for use in improving theater transportation for relatively small and light, high-priority LRUs.[5] Unlike the benefits of more DSESTSs, the benefits of this alternative will not appear as soon as conflict begins, because transportation does not affect availabilities until day 24, when items first start returning to the theater from the depot.

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[4]In general, although we might expect test equipment to be a more robust investment than stock in this respect, it is possible that as the test equipment becomes very expensive and/or unreliable, and as the range of items going across it widens (an IFTE-like environment), a class of items will emerge that is more cost effective to buy out than to repair, even under the highly variable demand conditions. Prime candidates might be items whose cost is very low relative to the test equipment and to other items tested on it, or items of low to moderate price with excessive diagnostic time requirements.

[5]This option assumes that the depot has sufficient capacity to handle both overflow and NRTS items and that this capacity cannot be simply transferred to theater units. The improved transportation then takes advantage of a depot capacity that must remain there whether used or not—otherwise, it might make more sense to disseminate some of that capacity into the theater rather than pay for extra transport. See App. A for a discussion of the more general case.

As Fig. 4.3 shows, this added transport capability dramatically improves M1 availability relative to an equivalent investment in Bradley spares inventory (the base case). Added transport capability also notably improves Bradley availability as the conflict progresses, although in the early days Bradley availability is worse than in the base case because an abundance of inventory has been given up with nothing yet received in return. Early Bradley availability is still relatively very high, however, and the decrement is small relative to the gains seen for both weapon systems as the conflict progresses. By contrast, an investment in spares yields only somewhat better Bradley availability early in the conflict, at the cost of substantially reduced M1 *and* Bradley availability if the conflict is prolonged.

Improved transport is also a more robust investment than Bradley inventory because it can adapt to item priority in a given scenario. This form of robustness is roughly analogous to that derived from additional DSESTSs (see Fig. 4.2), and we do not discuss it here in detail.

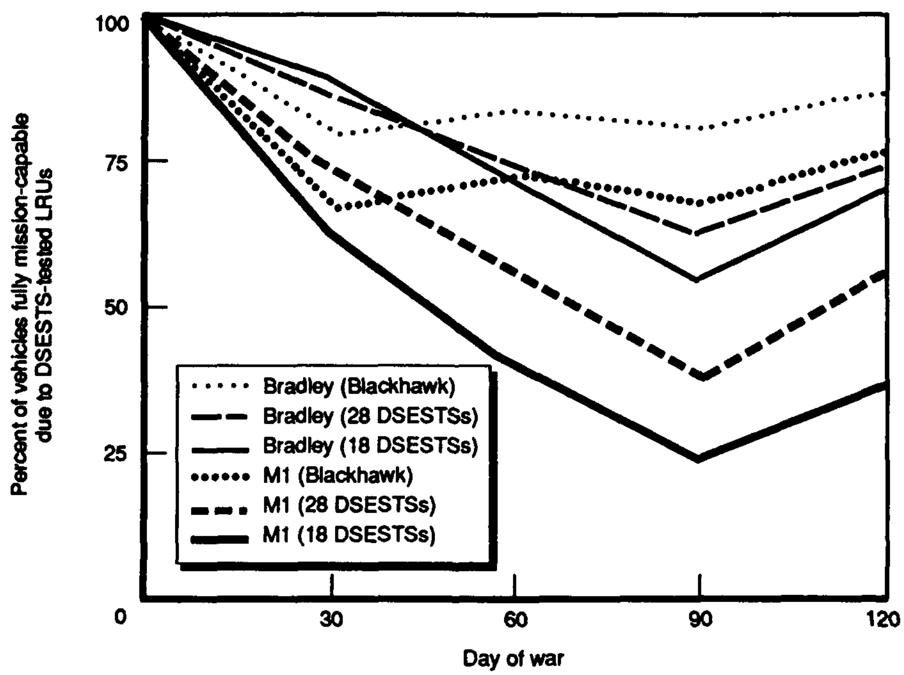

Fig. 4.3—Mean wartime availability of M1/BFV, exchanging Bradley spares inventory for improved theater transportation

It is interesting that Fig. 4.3 also shows that as the conflict progresses, improved transport results in more availability than does an equivalent investment in DSESTSs. Though the ability of improved transport to expedite NRTS items contributes somewhat to this result, the incidence of NRTS cases is not so high as to be a driving factor here. Rather, the model is weighing the contributions these alternatives make to decreasing the number of items in the "pipeline" to and from depot repair, which in turn improves weapon-systems availability. Adding more DSESTSs decreases the overflow into the depot pipeline. Improved transportation directly shortens the depot pipeline and thereby lessens the number of items in it. In this case, the Blackhawk alternative proves more effective.

Relocation of DSESTS Repair to the MSB

Improved transportation appears in this analysis to be a better investment than either stock or DSESTSs for increasing weapon-systems availability. However, as mentioned previously, this is partly because locating DSESTSs at FSBs limits their availability because of movement in the field and battle damage. Should the Army choose to locate DSESTS repair at MSBs, as suggested in Berman-1988, movement would decrease and loss from battle damage (as estimated in that study) might be relatively negligible.

Figure 4.4 shows the performance of an MSB-located system under the investment alternatives we have been considering. In comparing this figure with Fig. 4.3, we note that base-case (18 DSESTSs) availabilities are much improved over the FSB alternative. Moreover, Fig. 4.4 shows that, with repair at the MSB, investment in additional DSESTSs has a payoff comparable to that of improved transportation. The relative combat payoff of various resources, then, is conditioned not only on model inputs and estimates but also on the logistics structure.[6]

Although this analysis does not explicitly capture the issue, we note further that locating repair at the MSB could be expected to provide greater flexibility in the directing of repair effort within the division. It would allow collective resources to be directed toward units and missions of greatest need and could also help to better utilize resources that might otherwise stand idle (or remain focused on items of low priority) during times of low demand at particular FSB sites. The full effect of such enhanced flexibility and responsiveness can be seen in

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[6]We assume here that in relocating DSESTS repair at the MSB, the affected items (relatively limited in number) could be transported to the MSB using existing resources. Resources currently used to transport contact teams from MSBs to FSBs, for instance, might in the new configuration be used to bring items to the MSBs.

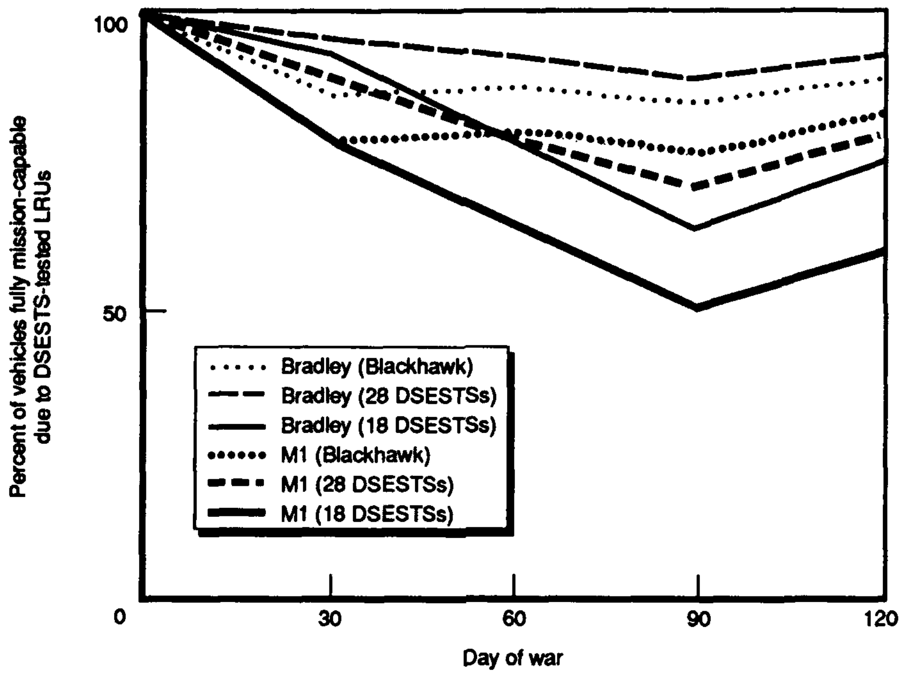

Fig. 4.4—Mean wartime availability of M1/BFV, when DSESTS repair is located at the MSB

our VISION research, which, as mentioned previously, focuses on more sophisticated management systems and uses more advanced versions of Dyna-METRIC.

THE VALUE OF A MULTIPLE-WEAPON-SYSTEMS APPROACH

This analysis shows how a notable improvement may be possible at constant cost when we consider the M1 and the Bradley as part of one system and therefore adaptable to resource trade-offs.

These results illustrate what can be achieved when traditionally compartmentalized resource decisions are made in light of one another. By considering the relative contributions of various resources to the performance of the support system, trade-offs can be exploited and investment priorities clarified. We note that, though the specifics may

change, these principles are equally applicable in any case where weapon systems contend for valuable and limited resources. In the earliest stages of decisionmaking in new IFTE-like environments, for instance, similar analyses might help provide a coherent rationale for resource investment and might thus increase the effectiveness achieved from limited budgets.

V. CONCLUSIONS AND FUTURE RESEARCH

CONCLUSIONS

In general, availabilities of weapon systems that share common maintenance facilities are interdependent. When support for these weapon systems is being assessed, each system should be considered in light of the others. Such an approach—integrating traditionally compartmentalized areas of analysis—can help the Army achieve more combat capability from limited budgets. This is particularly true in the area of high-technology systems.

Implications for the DSESTS

This study of the M1 tank and Bradley Fighting Vehicle finds that

- Some investments in Bradley spares inventory might serve the Army better if they were redirected toward (1) theater DSESTS resources or (2) improved theater transportation for selected high-priority items. These two alternatives show potential for significantly improving the availabilities of *both the Bradley and the M1* at constant cost. They are also more robust in the face of uncertain rates of item demand, because their *fungibility* helps the support system adapt to a range of different demand mixes within and across weapon systems.
- Moving DSESTS repair from FSBs to MSBs may substantially improve weapon-systems availabilities.

Implications for the IFTE

This analysis could serve to suggest a model for studying similar issues presented by the IFTE. Furthermore, because the IFTE may be used to test items from many weapon systems, even higher payoffs might be suggested by that analysis than by ours. However, planning scenarios may change dramatically as a result of recent world events, so such an analysis would need to be expansive. (See the discussion in App. A.)

FUTURE RESEARCH

The Role of Management Systems in Achieving Responsive Support

We consider the ability to prioritize repair and transportation across components and weapon systems to be indispensable in the shared maintenance facility environment. This implies *visibility* of assets and needs, as well as procedures to prioritize work loads accordingly. We are currently developing prototype management and decision support systems capable of implementing priority goals in a coordinated fashion across echelons, and we are assessing their payoffs for combat capability using more advanced versions of Dyna-METRIC than employed in this study.

Analysis of Depots

In the same way that the Bradley is best understood in light of the M1, so theater issues are better understood in light of the depot. The analytic framework suggested in this report and companion RAND publications (Berman-1988 and the Apache alternative structures document[1]) needs to be expanded to include richer modeling of depot operations, including GS repair capabilities. By better understanding the interplay between depot and theater, we can more properly assess theater issues, such as the possibility of placing additional repair in the theater. Studying such issues will yield more comprehensive insight into leverage points along the entire support system.

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[1]The Apache publication has been released in draft form only.

Appendix A

IMPLICATIONS FOR THE IFTE

The M1/Bradley DSESTS analysis could serve to suggest a model for a study of similar issues presented by the IFTE, and because of the IFTE's much greater scope of effect (serving up to 20 weapon systems), even higher payoffs might be suggested by such an analysis. The Army is well positioned to perform an IFTE analysis as a result of the IFTE COEA (Cost and Operational Effectiveness Analysis),[1] which built up a critical mass of expertise in the use of Dyna-METRIC at TRAC WSMR (White Sands Missile Range). This appendix briefly touches on major connections and important differences we see between our DSESTS analysis and one on the IFTE.

IFTE POLICY DECISIONS

It would not be appropriate to generalize the particular results of the DSESTS analysis to the IFTE, but we believe that the principles involved can and should be applied.

- A "systems" perspective that compares alternative *sets of policies* (concerning placement, inventory, special transport, and TMDE) in terms of cost and resultant weapon-systems availability. It is important to assess the simultaneous effects of these policy decisions on the support system because such decisions are interdependent. The value of investments in theater TMDE, for instance, depends in part on TMDE location in the theater, as well as TMDE capacity at the depot and the availability of timely transport to the depot.
- Exploration of a range of nontraditional alternatives in these areas to identify ways of achieving greater support effectiveness from limited budgets.

Pursuing these principles for the IFTE would probably lead to a more expansive analysis than that seen here for the DSESTS. Two areas in which this is particularly apparent are (1) IFTE placement

[1]U.S. Army TRADOC Analysis Command, White Sands Missile Range, *Intermediate Forward Test Equipment, Cost and Operational Effectiveness Analysis*, January 1989.

and (2) special transportation investments. (In the discussion that follows, we focus on the IFTE Base Shop Test Facility (BSTF) and do not address Contact Test Sets or depot-specific equipment.)

IFTE Placement

We have seen that moving DSESTSs from FSBs to MSBs could dramatically improve weapon-systems availabilities (Sec. IV) and noted how dispersion of test equipment can hamper the ability to direct its use toward larger goals (Sec. III). Clearly, test-equipment placement can significantly influence support effectiveness. For the IFTE, the placement decision is more complex and potentially more pivotal.

At the theater level, a wider range of alternative placements should be considered than simply the MSB-versus-FSB case examined in this DSESTS analysis. The IFTE BSTF can serve a much wider range of weapon systems than the DSESTS can; hence, consolidation at higher levels such as corps or even echelons above corps may best capture the advantages of *fungibility*.[2] (See Sec. IV for a discussion of the value of testing capability that is fungible across weapon systems.)

The balance of BSTF between the theater and the depot also deserves renewed scrutiny. This is in part because improved transportation investments can change how one views that balance, as discussed below. More pressing, however, is that the meaning of "theater" may change drastically as a result of the fundamental changes now taking place in the scenario driving Army planning. Should that scenario indeed move away from a massive, multi-corps theater to one focusing on smaller-force missions, the depot/theater balance may require rethinking. One reaction might be to plan for an emphasis on depot (over theater) as a source of concentrated capability for supporting smaller missions of various types and in various locations, through use of a kind of special LRU transport capability. In any event, such alternatives should be generated as clearer visions of the future theater(s) become available.

Improved Transportation

The DSESTS analysis demonstrated that improved theater transportation for selected high-priority items could notably increase weapon-systems availability when excess test capacity exists at the

[2] Of course, it is unlikely that each BSTF would be outfitted with the full complement of Test Program Sets (TPS). This implies that in addition to the issue of BSTF placement would be the (perhaps embedded) issue of allocating TPS among BSTF—a problem that may be analogous to that of placement of weapon-systems-specific TMDE.

depot (Sec. IV). Alternatively, the IFTE COEA[3] demonstrated that special transport of TMDE-tested items is of little use if depot test equipment is already saturated, since items are speedily expedited from the theater only to wait in long queues at the depot.

Clearly, what is important is to plan for a *balance* between depot test capacity and transportation, so that the existing capacity can be fully utilized. This implies that decisions on placement and special transport should be linked. For example, when considering a support structure that relies significantly on depot repair capability, sufficient investment in special transport should be included to allow depot capacity to be used in a timely enough manner to influence the war. On the other hand, when considering a support structure with greater self-sufficiency in the theater and little reliance on depots, less emphasis might be required on special transport arrangements.

CAPTURING KEY WARTIME FACTORS

We believe that some key wartime conditions should be represented in the analysis if the Army is to achieve an IFTE support structure that is responsive to wartime needs. (We assume that the goal is to design a support system that is not merely sufficient for peacetime activity, but one that is high in readiness for the onset of war.) Some of these conditions were represented in the DSESTS analysis; others were not. But we believe that they should be an important aspect of a similar analysis for the IFTE. The first condition is

- Degradation of test-equipment availability due to movement and battle damage. Movement and battle-damage effects are a function of TMDE location in the theater and hence should influence TMDE placement.

Other conditions needed to capture the potential benefits of TMDE consolidation are as follows:

- Variability in operating tempos over time and across units, hence simulating the variability in work loads that consolidation can help to smooth.
- Modeling of the priority repair and distribution needed to manage consolidated assets effectively. A new version of Dyna-METRIC (version 6), now available, has a significantly expanded ability to represent such management, making it appropriate for IFTE analyses.

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[3]U.S. Army TRADOC Analysis Command, *Intermediate Forward Test Equipment*, pp. 46–47.

- More suitable measures of effectiveness. The most commonly used measure of effectiveness in Dyna-METRIC modeling—mean availability over all weapon systems—is too aggregated to reflect the gains in responsiveness to particular unit missions that consolidation could bring. Less aggregated measures would be sensitive to unit-mission priority and would come closer to reflecting support to units as they individually engage or disengage from combat situations. One such measure might be the number of mission hours each unit is able to accomplish over time, which would emphasize the value of high availability at the time of most intense tempos. Another might be the ability to keep many units above some minimum level of availability (which might vary with unit mission), even though some have much heavier work loads than others. Such measures can be extracted easily from Dyna-METRIC.

Appendix B

DYNA-METRIC INPUTS

We first note that, as mentioned in Sec. III, the analysis employs an operational scenario that assumes a large-scale conflict between NATO and the Warsaw Pact in Central Europe. Although recent events in Europe appear to have dramatically decreased the likelihood of such a conflict, we believe that the *support principles* on which the analysis focuses are still relevant, if not more so, for future scenarios.

REPAIR DATA

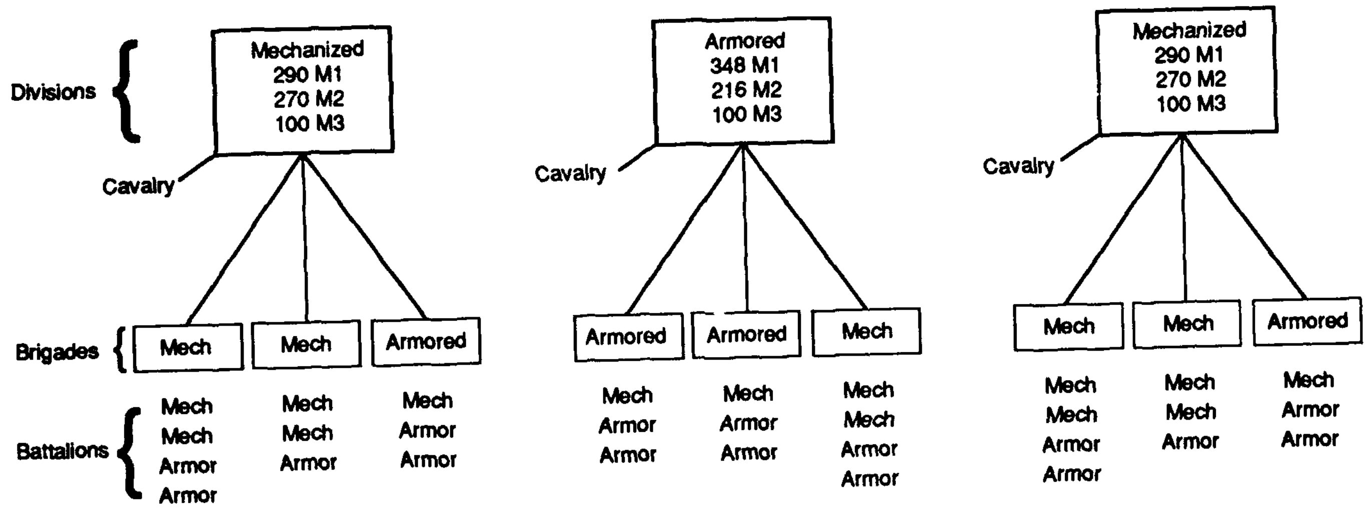
Maintenance and repair process data were derived from analyses of SDC data. These data were based on a sample of three M1 tank battalions and five M2/M3 Bradley battalions and include information on rates of failure and of removal for LRUs, test equipment use, LRU and SRU (Shop Replaceable Unit) repair times, NRTS rates, and indenture relationships of systems, LRUs, and SRUs. M1 data are largely from 1985, as used in Berman-1988, except for removal rates, for which we used 1985–1987 data. Bradley data span calendar years 1984–1986.

FORCE STRUCTURE

We model one corps and, in particular, all division-owned M1 tanks and Bradleys in that corps. We exclude M1s belonging to the cavalry regiment or to the corps as a whole. The corps comprises three divisions, one armored and two mechanized, with M1/M2/M3 allocations as shown in Fig. B.1.

OPERATIONAL SCENARIO

We use the brigade as the unit of analysis. Each brigade is assigned a per-tank combat-hour activity level for each day of conflict, which applies to all tanks available to the brigade that day. This study employs the Army Concepts Analysis Agency's P90E COSAGE scenario of a Central European conflict to drive demands in the Dyna-METRIC model. The scenario provides postures for each brigade (or



	M1	M2	M3
Armor battalion	58		6
Mech battalion		54	6
Cavalry squadron			40

Fig. B.1—Force structure of a three-division corps for the Dyna-METRIC model

fraction of a brigade) for each day of a 120-day scenario. These include offense, intense defense, and a light defense/static posture. The Armor Center Directorate model of battalion-level force-on-force combat provides average per-tank combat hours for each type of posture. These range from 7.7 hours per day for light defense/static to 15.1 hours per day for full offense.

Data on M2/M3-brigade operating tempos obtained from the U.S. Army Logistics Center indicate that M2/M3 vehicles follow the M1 very closely for these postures; hence, those vehicles were assigned the same scenario tempos as the M1. Tempos for M3 in the cavalry squadron, however, are not as closely allied to the M1 and so were treated separately. They were simply set at an average of 10.0 hours per day for all postures, and variations in that rate do not affect results notably, since these vehicles represent only 11.3 percent of all Bradleys modeled.

SPARES INVENTORY

Table B.1 shows Bradley spares inventory figures used in this analysis. (M1 figures, by comparison, average around 50 units of each item for the entire corps.) War reserve stock requirements were obtained from the Tank and Automotive Command (TACOM) and from the Armament Munitions and Chemical Command (AMCCOM). In cases where the raw data represented worldwide war reserve figures,

Table B.1

BRADLEY INVENTORY LEVELS USED IN DYNA-METRIC ANALYSIS

LRU	Authorized Stockage List	Corps' Slice of Worldwide War Reserve Requirement
Electronic control assembly	6	838
Vehicle distribution box	8	270
Turret distribution box	8	280
Gunner's hand station	6	86
Relay assembly	7	276
Weapon control box	8	18
Turret position indicator	6	0
Power converter	6	56

roughly one third of that was considered to be for our corps. War reserve LRU stock was assumed to be positioned at the MSB. In addition, each division's Authorized Stockage List was located at the FSB and was derived from a recent Support List Allowance Computation (SLAC) from Army Materiel Command (AMC) headquarters.

Generally, the levels actually funded in peacetime will fall far below these planning figures. In our focus on wartime support, however, we do use these figures, since they represent the Army's intended use of funds that become available in such an environment.

TEST-EQUIPMENT AVAILABILITY

Based on discussions with Army personnel on expected unit movements and time to relocate, availability of the DSESTSs is estimated at 60 percent when they are located at FSBs and 70 percent when they are at MSBs.

TRANSPORTATION

Transportation data for M1 tank items were obtained from the Logistics Intelligence File (LIF). These data were reviewed with other LIF data and with the Uniform Materiel Movement and Issue Priority System (UMMIPS) standards to arrive at the nominal estimates of a 21-day order-and-ship time for serviceables and a 28-day retrograde time for repairables.

In any major European contingency, strategic and tactical transportation will be overloaded. A 30-day cutoff time for repair parts, supply, and retrograde to CONUS depots was assumed because most inter- and intra-theater transportation is involved with unit movement during this period. For alternatives using assured transportation, a 10-day cutoff time was assumed because of inevitable lags in establishing support systems in the midst of a major deployment.

ATTRITION OF VEHICLES

It was assumed that sufficient float vehicles were available to replace those lost to combat kills. While information on M1 float vehicles supports this assumption, no such data were available for the Bradley. Hence, this assumption was made in the absence of better evidence. See subsection "Sensitivity of Results" in Sec. III for a note on the implications.